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SEABED ANCHOR

This invention relates to a seabed anchor including in particular so-called "suction anchors", and to a method of embedding such an anchor.

For the exploitation of hydrocarbon reservoirs that lie under the seabed, it is known to use offshore structures that are anchored to the seabed. The offshore structures commonly include equipment for drilling wells through the seabed into hydrocarbon reservoirs beneath the seabed, and for subsequently extracting hydrocarbons from the wells. An offshore structure may be a floating structure that is tethered to one or more seabed anchors to keep the structure at a desired location; alternatively, an offshore structure may be a non-floating structure that is supported on a foundation which rests on or in the seabed. In either case, safety and reliability require that the seabed anchor or foundation be stable against disruption by environmental phenomena and/or structural loading. It is known for closed caissons, piles, and gravity bases (massive ballast-filled slab-form structures of steel or reinforced concrete) to be used as seabed anchors or foundations. When the seabed soil conditions permit, anchors and foundation structures are preferably embedded in the seabed (as distinct from merely resting on top of the seabed), with the consequent improved stability depending upon the mechanical properties of the seabed soil (e.g. on shear strength, cohesion, specific gravity, etc.), and also on the size of the anchor or other structure. Generally, embedded anchors are slender so as to ensure that a substantial quantity of seabed soil resists movement of the anchor under the influence of external forces applied to the anchor.

Anchors may be embedded in the seabed by one of the two following methods:

(i) a hollow anchor having a closed top and an open bottom is placed upright on the seabed, and the interior of the anchor is evacuated by a suction pump such that external hydrostatic pressure applies forces to the anchor that cause the anchor to penetrate the seabed and become embedded in the seabed;

(ii) a hollow anchor having open top and bottom ends is mechanically driven into the seabed soil by application of a vibratory mechanism, or by repeated application of a large hammer (i.e. by "pile driving" techniques).

For the embedment of anchors or other structures in seabed soil at great sea depth, method (i) is preferred since seabed soil conditions are generally soft (i.e. the seabed soil is generally mud or silt in a more or less fluent state) and the installation equipment is much lighter and easier to deploy and operate than the equipment required by method (ii). Anchors embedded by method (i) are known as "suction anchors" or "suction piles". The present invention, in its broadest aspect, is not limited to suction anchors, however.

The anchors described are designed to rely upon friction between seabed soil and the skin of the anchor, with the result that such anchors are generally very tall for a given minimum holding resistance (i.e. a force below which the anchor can be relied upon to resist dislodgement from the seabed), such resistance depending on the characteristics of the seabed soil. Consequently, an anchor fabricated on land and transported whole to a marine location where the anchor is to be embedded in the seabed is difficult to transport and install, and may prove inefficient at withstanding design loads due to uncertainties associated with soil characteristics.

It is an object of the invention to provide an anchor and method of deployment thereof having improved performance, given its size and weight.

According to a first aspect of the present invention there is provided a seabed anchor in the form of a caisson having a longitudinal axis and comprising a caisson side wall, an open caisson bottom and a closed caisson top that together define an interior volume of the caisson, characterised by seabed soil retaining means for retaining seabed soil displaced during embedment of the anchor in seabed soil in a direction generally

downwardly along said longitudinal axis such that the weight of seabed soil retained by the seabed soil retaining means adds to the force required to pull the embedded anchor out of the seabed.

Said anchor may be provided with a fluid connection to the interior volume, whereby suction can be applied to cause embedment of the anchor in seabed soil.

Said seabed soil retaining means may comprise at least one container having an opening arranged to admit seabed soil during embedment of the anchor in the seabed. Said container may be constituted by an open-topped hopper and preferably has a downwardly reducing external cross-section to minimise resistance to upward movement of seabed soil past the container during embedment of the anchor.

The container in one embodiment has a conical exterior, the apex of the cone oriented to penetrate the soil during embedment. The internal and external form of the container need not be the same, but a simple conical wall will suffice, and a more elaborate construction is likely to be heavier, defeating the object to some extent.

The seabed soil retaining means is preferably located entirely within the interior volume of the caisson, and the seabed soil retaining means is preferably located adjacent the caisson top to receive and retain seabed soil displaced during latter stages of anchor embedment.

According to a second aspect of the present invention there is provided a method of embedding a seabed anchor according to the first aspect of the present invention in a seabed composed of soil, the method comprising the steps of deploying the anchor onto the seabed with the longitudinal axis of the anchor aligned substantially in a predetermined direction such that an open lower end of the anchor (or an opening in the lower end of the anchor) contacts the seabed soil, and applying forces to the anchor directed generally downwardly along the longitudinal axis of the anchor such as to force the anchor into the seabed soil and cause seabed soil to enter the interior of the anchor eventually to displace seabed soil into the seabed soil retaining means of the

anchor whereby the anchor is embedded in the seabed substantially in said predetermined direction and the weight of seabed soil retained in the seabed soil retaining means adds to the force required to pull the embedded anchor out of the seabed soil.

Said applied force may be derived by applying suction to the interior volume of the anchor.

In said second aspect of the invention, said predetermined direction may be substantially vertical, or said predetermined direction may be partly vertical and partly horizontally directed in a selected bearing such as to embed the anchor into the seabed substantially in a predetermined non-vertical direction that optimises resistance of the so-embedded anchor to withdrawal by non-vertical loads.

A known gravity base can be adapted to form a third aspect of the invention by being provided with a seabed soil retaining means such that the gravity base can be embedded in fluent seabed soil by a method corresponding to the second aspect of the invention and thereby forming a fourth aspect of the present invention. Where the gravity base has a single open-bottom, closed-top cell, that cell can be adapted in like manner to the anchor of the first aspect of the present invention. Where the gravity base has a plurality of open-bottom, closed-top cells, each cell can be individually and respectively adapted in like manner to the anchor of the first aspect of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings wherein:

Fig. 1 is a simplified sectional elevation of a first embodiment of suction anchor in accordance with the invention;

Fig. 2 is a simplified transverse cross-section of the first embodiment, taken in the horizontal plane denoted II-II in Fig. 1;

Fig. 3 illustrates the first embodiment in an initial stage of its embedment in fluent seabed soil;

Fig. 4 illustrates the first embodiment in an intermediate stage of its embedment in fluent seabed soil; and

Fig. 5 illustrates the first embodiment in a final stage of its embedment in fluent seabed soil.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Referring first to Figs. 1 and 2, a suction anchor 10 comprises a caisson 12 having a side wall 14 that is substantially circular about a longitudinal axis 16 that is vertical and central when the anchor 10 has the alignment illustrated in Fig. 1. The side wall 14 is generally shaped as a right cylinder, that is a uniform cylinder having a vertical wall of substantially constant radius about the vertical and central longitudinal axis 16. The caisson wall 14 is fabricated of welded steel plates, and is stiffened by vertically distributed steel ribs 18 that extend circumferentially around the internal surface of the wall 14. The ribs 18 have an upwardly open channel form to increase the resistance presented by the wall 14 to withdrawal from embedment in mud or other seabed soil (see Fig. 5). The extent to which the upwardly open ribs 18 hold a weight of seabed soil that may add to anchor withdrawal force is, like similar features in prior art anchors, so minimal as to be negligible in comparison to the relatively massive seabed soil retaining and weight-adding arrangement to be described further below.

The bottom edge 20 of the caisson side wall 14 presents a downwardly directed knife-edge for ease of penetration of seabed soil (see Figs. 3-5). The caisson bottom 22 (bounded by the bottom edge 20) is open and unimpeded by any form of transverse closure. As an alternative to an open bottom (22), the caisson bottom may be partially

closed by a plate or grid (not shown) having one or more apertures of a total area sufficient to allow an adequately free throughflow of mud or other fluent seabed soil when suction is applied to the interior volume of the caisson.

The top edge 24 of the caisson side wall 14 is continuously welded to the periphery of a top end wall 26 of steel plate to form an airtight connection thereto and thereby close the top end of the caisson 12. A suction vent in the form of a connector 28 is welded to the centre of the top end wall 26 for the fluid-tight connection of the interior of the caisson 12 to an external suction pump (not shown in Figs. 1 or 2; but see Fig. 4 and related description below). As an alternative to locating the suction vent in the caisson top end wall 26, the connector 28 (or any other suitable form of suction vent) could be attached to the caisson side wall 14 near its top edge 24.

The caisson side wall 14, the top wall 26, and the caisson bottom 22 bounded by the bottom edge 20 together define the interior volume of the caisson 12. Passage of fluids (e.g. air, seawater, and fluent mud) into and out of the interior volume of the caisson 12 can take place only through open bottom 22 and/or the connector 28.

It goes without saying that, to function, the anchor is also provided with attachment points, not shown in these drawings, for a chain or other tether, connected typically to a floating structure of some kind. The tether is generally attached to one side of the anchor, rather than on top. The tether is conventionally attached to the anchor prior to the embedment process. However, techniques are available for attaching the main tether after installation of the anchor, as disclosed in our co-pending international application PCT/EP02/01959, not published at the priority date of the present application.

The suction anchor 10 as so-far described is substantially conventional, and the further features that convert a known suction anchor into the first embodiment of the present invention will now be detailed with further reference to Figs. 1 and 2.

The caisson 12 is internally fitted with soil retaining means in the form of a conical hopper 30 that is aligned point-down and is substantially symmetrical about the aforementioned vertical and central longitudinal axis 16. The bottom point 32 of the conical hopper 30 is supported by an array of eight equi-spaced horizontal struts 34 that extend radially from the point 32 to the caisson wall 14 to carry the weight of the hopper 30 together with the weight of any material held in the hopper 30. The hopper 30 has a conical wall 36 that diverges outwardly and upwardly from the bottom point 32 to a circular upper edge 38. The top of the conical hopper 30 is joined to the caisson wall 14 by an annular grid 40 that laterally supports the upper edge 38 (the annular grid 40 is shown in Fig. 1, but is omitted from Fig. 2 for clarity). As well as laterally supporting the top of the hopper 30, the annular grid 40 also allows fluent mud to pass upwardly through the grid 40, as will subsequently be detailed with reference to Fig. 4. The top of the hopper 30 (bounded by the upper edge 38) is open and unimpeded by any form of closure, while the bottom of the hopper 30 is closed to the passage of all fluids. The hopper 30 is located within the caisson 12 such the bottom of the hopper 30 (i.e. the bottom point 32) is above mid-height within the caisson 12, while the top edge 38 of the hopper 30 is not greatly below the top end wall 26. The conical hopper 30 serves as a seabed soil retaining means of the anchor 10, as will now be detailed with reference to Figs. 3-5. For the sake of clarity and simplicity the longitudinal axis 16 is not depicted *per se* in Figs. 3-5.

Fig. 3 depicts the preliminary stage of embedment of the suction anchor 10 in a submerged seabed 100 that is composed of fluent mud. (This seabed mud is sufficiently fluent as to tend to flow when subjected to adequate force, whether due to gravity or pressure differentials, the mud also being sufficiently denser than the ambient seawater as to tend to sink in the seawater.) Initially, the connector 28 is unconnected to any external pump and freely connects the interior volume of the caisson 12 to the surrounding seawater. The anchor 10 is set down on the seabed 100 in an upright position (with the longitudinal axis 16 substantially vertical) and with the bottom edge 20 lowermost, by means of a hoist (not shown). Since the bottom edge 20 presents a downwardly directed knife-edge (as previously described) and since the interior volume of the caisson 12 is freely vented through the open connector 28 to the

ambient seawater, the dead weight of the anchor 10 causes the bottom edge 20 to penetrate the fluent mud of the seabed 100, with fluent seabed mud flowing upwardly through the open container bottom 22, until the anchor 10 reaches the seabed penetration stage depicted in Fig. 3.

Referring now to Fig. 4, an external pump 200 is temporarily coupled to the connector 28, the pump 200 being any suitable form of seawater pump. Although shown close to the anchor, pump 200 may well be on board a ship at the surface. The pump 200 is operated to suck seawater out of the interior volume of the caisson 12 through the connector 28 (flow 202), this evacuated seawater being discharged (flow 204) through the pump outlet 206 into the surrounding ocean. The suction induced by operation of the pump 200 causes the pressure in the interior volume of the caisson 12 to fall significantly below the external pressure of the ambient seawater, consequently inducing a hydrostatic pressure imbalance denoted by the arrows 300. This pressure imbalance 300 acts on the top wall 26 in a downward direction and tends to drive the anchor 10 more deeply into the seabed 100 generally downwardly along the substantially vertically directed longitudinal axis 16. (Inwardly directed horizontal forces on the caisson side wall 14 induced by the internal suction tend to act towards the central axis 16 in mutually opposing directions, and thereby be self-cancelling.) As the anchor 10 increases its vertical penetration of the seabed 100, fluent mud drawn by the pump-induced suction through the open bottom 22 and upwardly into the interior volume of the caisson 12 rises up the interior of the caisson 12 (as denoted by the arrows 102), eventually to flow upwardly through the annular grid 40 and overtop the upper edge 38 of the conical hopper 30. The mud thereupon falls into the conical hopper 30 (as denoted by the arrow 104) where the mud accumulates, this mud being retained in the closed-bottom hopper 30 by the combination of the tank wall 36 and the density of the mud being greater than the density of the seawater filling those parts of the interior volume of the caisson 12 that are not currently occupied by indrawn mud. As the anchor 10 penetrates more deeply into the seabed 100, the upward passage (102) of mud past the exterior of the hopper 30 is minimally impeded by the conical shape of the tank wall 36 (in comparison, for example, to the mud-flow-impeding effect of a hypothetical cylindrical soil-retaining tank with a flat horizontal bottom).

Operation of the pump 200 is continued until the anchor 10 achieves the seabed penetration extent depicted in Fig. 5, wherein the interior volume of the caisson 12 is largely filled with seabed mud that has been sucked through the open bottom 22 and into the interior volume of the caisson 12 by operation of the pump 200. In particular, the seabed soil retaining hopper 30 is substantially filled with in drawn mud. Deficiencies in filling of the hopper 30 to its maximum capacity will correspondingly diminish (but not destroy) the useful effect of the hopper 30, the advantage of the hopper 30 remaining for so long as the hopper 30 is at least partly filled. When the caisson 12 has been filled with seabed mud to a satisfactory extent, the pump 200 is disconnected from the connector 28 and withdrawn for future use elsewhere. Disconnection and withdrawal of the pump 200 concludes the process of embedding the anchor 10 in the seabed 100, other than for any inspection and/or testing deemed necessary or desirable. The anchor 10 remains embedded in the seabed 100, where the embedded anchor 10 presents a resistance to being pulled out of the seabed 100 which is greater than the resistance of a similarly dimensioned but conventional suction anchor (i.e. a suction anchor that lacks a seabed soil retaining means) by an extent at least equal to the weight of the seabed mud retained in the hopper 30 at the conclusion of embedment of the anchor 10 in the seabed 100. The embedded anchor 10 can then be utilised as though it were a similarly dimensioned but conventional suction anchor that was exceptionally well embedded, or a much larger but conventional suction anchor that was conventionally embedded.

The vertically embedded anchor 10 will resist loads that are directed vertically upwards, and will also resist loads that are a vector combination of horizontal and vertically upward load components (including but not restricted to loads whose vertical component is predominant). In order to optimise embedment of the anchor 10 to withstand loads predominantly directed in a specific non-vertical direction, the anchor 10 may alternatively be set down on the seabed 100 with the longitudinal axis 16 of the anchor 10 aligned substantially in that specific non-vertical direction, such that the anchor 10 is embedded in the seabed 100 generally along that specific non-vertical direction. As mentioned earlier, the point of attachment of the load normally at one

side of the anchor, to avoid loads tending to pull the anchor out along its axis 16. It will be understood that the anchor having soil retained therein will resist such loads better than an anchor relying on friction alone.

The first embodiment of the present invention has been presented as a suction anchor, but the invention can also be applied to other structures intended for embedment in a seabed. For example, seabed anchors according to the first aspect of the invention can be embedded in seabed soil without using suction, by placing the anchor on the seabed and applying generally downward forces to the anchor to cause the anchor to become embedded in the seabed soil.

The soil retaining means need to be located internally of the anchor body and need not be a single centrally located container. Multiple containers, if desired, can be distributed both vertically and around the periphery of the anchor body.

Other modifications and variations of the invention can be adopted without departing from the spirit and scope of the invention as defined in the appended claims.